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User's Manual for the GPS Orion-S/-HD Receiver

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Scope and Applicability

This manual provides a user’s guide for the DLR’s GPS Orion receivers for space and high dynamics applications. It describes the hard and software interfaces required for operating the receiver in standalone and embedded applications. Information in this document supplements and supercedes related sections of the GPS Orion Product Brief [1] and the GP2000 Series Demonstrator Board User’s Guide [2]. It is applicable for s/w versions D06H (Orion-HD) and D07N (Orion-S).

Acronyms and Abbreviations

A	Ampere
AGC	Automatic Gain Control
ASCII	American Standard Code for Information Interchange
C/N_0	Carrier-to-Noise Ratio
COM	Communication
dB	Decibel
DC	Direct current
DLR	Deutsches Zentrum für Luft- und Raumfahrt
EPROM	Erasable Programmable Read Only Memory
FLL	Frequency-Locked Loop
GPS	Global Positioning System
GSOC	German Space Operations Center
I/F	Intermediate Frequency
IIP	Instantaneous Impact Point
IQ	In-phase and Quadrature (correlator output)
L1	GPS frequency (1575.42 MHz)
LEO	Low Earth Orbit
LNA	Low noise amplifier
MITEL	Company name
NMEA	Nautical Marine Electronics Association
NVM	Non-Volatile Memory
ORION	Product name
PC	Personal Computer
PLL	Phase-Locked Loop
PPS	Pulse-per-second
PRN	Pseudorandom Noise
R/F	Radio Frequency
RAM	Random Access Memory
RX	Receiver
SAW	Surface Acoustic Wave
SMA	Sub Miniature Assembly
SNR	Signal-to-Noise Ratio
SV	Space Vehicle
TC	Telecommand
TCXO	Temperature Controlled Oscillator
TM	Telemetry
TTL	Transistor-Transistor-Logic
TX	Transmitter
UART	Universal Asynchronous Receive and Transmit
V	Volt
W	Watt

1. Introduction

1.1 GPS Orion Receiver

The GPS Orion receiver represents a prototype design of a terrestrial GPS receiver for 12 channel single frequency tracking built around the Mitel (now Zarlink) GP2000 chipset ([3], [4]). The receiver main board comprises a GP2015 frontend and DW9255 saw filter, a GP2021 correlator as well as an ARM60B 32-bit microprocessor. It can be supplemented by an optional interface board featuring a switching regulator, serial line drivers (RS 232) and a backup battery.

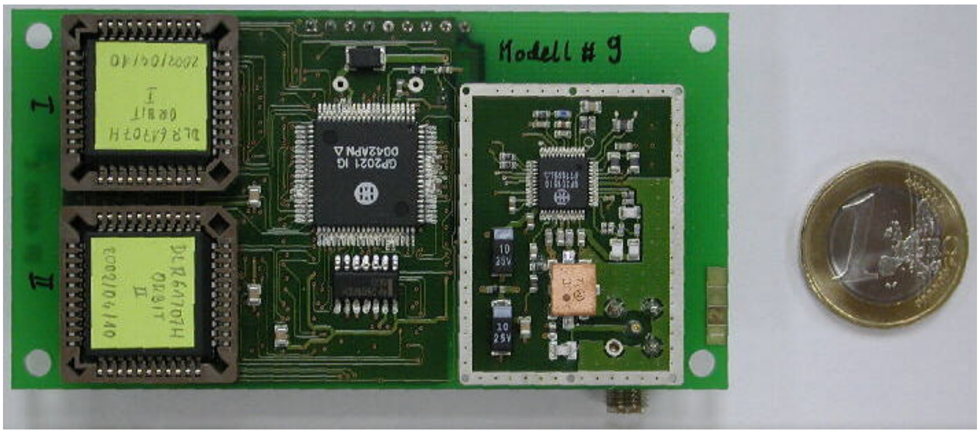


Fig. 1.1 GPS Orion main board

A basic software for the GPS Orion receiver has earlier been made available by Mitel Semiconductor as part of the GPS Architect Development Kit. It is restricted to purely terrestrial applications and has received numerous extensions and modifications to provide accurate navigation under the rapidly varying signal conditions encountered in typical space missions. Key upgrades include enhanced tracking loops, a synchronization of measurements to integer GPS seconds, the provision of precise carrier phase measurements, a revised navigation algorithm, as well as a software based aiding of the signal acquisition using reference trajectory data. In addition to the above software changes, the original hardware design has been amended by a supplementary pin for output of the pulse-per-second signal.

1.2 Functional Overview

DLR’s family of GPS Orion receivers comprises various firmware versions for space and high dynamics applications. Available software configurations are:

- Orion-S for low Earth satellites and formation flying
- Orion-HD for high dynamics platform like sounding rockets and reentry vehicles

Features common to all receiver models are summarized below.

- 12 fully independent tracking channels
- 2-bit sampling
- 3rd order PLL with FLL assist
- Low noise code, carrier and Doppler measurements
- Acquisition aiding using reference trajectory information
- Navigation update rate of up to 2 Hz
- Configurable ASCII output messages in WinMon and NMEA format
- Pulse-per-second signal
- Low power consumption (2 W at 5 Volts)

- Small form factor (50 x 95 mm) and weight (50 g)
- Sufficient radiation tolerance LEO usage
- Battery buffered non-volatile memory and real-time clock
- Two serial ports
- Discrete input pin
- 5V supply for active antenna (16-28dB)
- OrionMonitor control software for Windows PCs

A hardware description of the Orion-S/HD receiver is provided in Chap. 2 of this manual. Chap.3 addresses the receiver operation and the command and log functionality is described in full detail in Chap. 4.

1.3 Receiver Versions

The Orion receiver is available in various versions, which basically differ by the employed receiver software. Aside from the standard receiver (Mitel reference design [3], [4]), which is restricted to terrestrial applications, a space (-S) version and a high dynamics (-HD) version are available. These employ specific trajectory models to enable a safe and rapid signal acquisition under rapid motion of the host vehicle. For satellites in low Earth orbit, aiding is provided by an analytical orbit model using twoline elements, whereas a set of piecewise polynomials is employed to approximate the trajectory of ballistic vehicles (sounding rockets, reentry capsules) in the HD version. Various commands specific to each of these versions are provided to load, dump and use the respective aiding information.

The two versions also differ by their choice of FLL/PLL loop settings that are adapted to the specific application needs. A narrow bandwidth of the carrier tracking loop is chosen in the Orion-S receivers to achieve the most accurate carrier phase measurements under typical line-of-sight accelerations of 1 G. Wide bandwidth settings, in contrast are chosen for in the HD receivers to accommodate the extreme dynamics of a powered flight and the re-entry shock.

Finally, a relative navigation mode is offered by the Orion-S receiver to support its use in basic formation flying and rendezvous & docking applications.

A detailed account of the prototype software for the GPS Orion receiver is given in the GPS Architect Software Design Manual [5]. Subsequent modifications for the S and HD version are described in [6].

2. Receiver Hardware

2.1 Main Board

A block diagram of the GPS Orion receiver main board is shown in Fig. 2.1 ([4]). The receiver is designed to work with an active antenna and +5 V power supply for the preamplifier is provided on the central antenna feed.

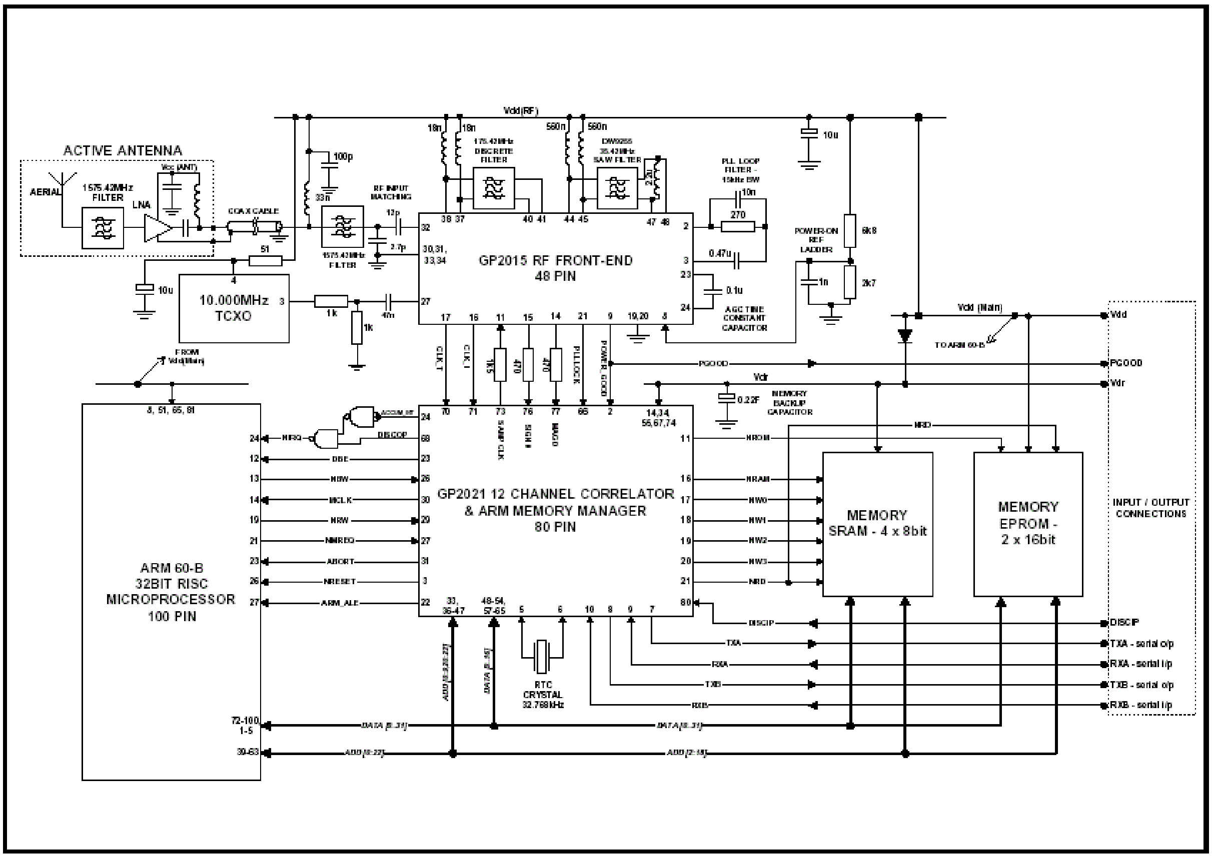


Fig 2.1 Block diagram of the GPS Orion receiver main board (from [4])

After passing an R/F ceramic filter, the L1 signal (1575.42 MHz) is down-converted and digitized in the GP2015 front-end chip [7]. An external discrete filter and a DW9255 SAW filter [8] are used to filter the first (175.42 MHz) and second (35.42 MHz) intermediate frequencies, while an on-chip filter is used for the third analog IF (4.31 MHz). Finally, the signal is digitized and sampled to create a digital IF of 1.405 MHz with 2-bit quantization. The fundamental reference frequency for the mixing process is provided by a 10.0 MHz TCXO with a specified stability of 2.5 ppm. It also used to derive a 40 MHz clock frequency for the correlator.

The subsequent signal processing is performed in the GP2021 correlator chip [9], which provides 12 fully independent C/A code correlator channels. It also offers two UART ports for external I/O as well basic memory management capabilities that can be used when working with the ARM micro-processor. The GP2021 chip furthermore maintains a low accuracy real-time clock fed by a 32.568 kHz crystal. It also derives a 20 MHz clock frequency for the ARM processor.

All software tasks operate in the 32-bit P60ARM-B micro-processor [10] that provides a peak performance of 20 MIPS and has a typical spare capacity of 35% at 1 Hz navigation rate and 25% at 2 Hz. Upon start-up (or a reset) of the receiver, a boot loader (stored in EPROM) is activated that copies the executable code and initialisation data from the EPROM into the

RAM memory. The EPROM is arranged into two 16 bit wide chips (256 kB total), while RAM is partitioned into four 8 bit wide memory chips with a total size 512 kB. The RAM memory contents can be maintained by a dedicated backup power supply line with a current of approximately 0.1 mA.

The main board offers an SMA (or MCX) connector for the GPS antenna. It is connected to the interface board via a 9-pin header that provides two bi-directional serial lines, the main and backup power supply, an input discrete and a reset line. Optionally, a tenth pin is made available for the pulse-per-second signal. A summary of the pin assignment is provided in Table 2.1.

Table 2.1 Pin assignment for GPS Orion interface connector

Pin	Function
1	Ground
2	Vdr (memory backup positive supply)
3	RX B serial input
4	RX A serial input
5	TX B serial output
6	TX A serial output
7	Discrete input line (used as a "lift-off" signal)
8	Vdd level sense circuit output (used as a "reset" if connected to GND)
9	Vdd (+5V prime power supply input)
10	PPS output (optional)

General physical and electrical parameters of the Orion main board are summarized in Table 2.2. The GPS Orion receiver and its components have not been validated for space applications. Nevertheless, limited information on the radiation hardness of the core chipset suggests it's suitability up to a total dose of about 15 krad [11]. However, no latch-up protection is presently provided to safeguard against destruction of CMOS circuits under the action of heavy ions. Other than the standard Orion receiver, the main boards of the Orion-S and -HD receivers are not equipped with a "supercap" capacitor, since this is not considered vacuum-proof. This means that the non-volatile memory and real-time clock is lost whenever the main board is disconnected from the backup power supply (pin 2).

Table 2.2 Physical and electrical parameters of GPS Orion main board

Parameter	Value
Dimension	95mm x 50mm x ~10mm
Weight	ca. 50g
Operations Temperature	-40°C to +85°C (as per [1])
Storage Temperature	-50°C to +110°C (as per[1])
Main power supply	+5V DC (+/- 10%), 400 mA (2W)
Backup power supply	>+2.2V DC, ca. 100 µA
Data I/O levels	CMOS TTL (0V, +5V)
RF input	
Connector	SMA (or MCX)
Active antenna power supply	+5V DC, 50 mA
Impedance	50Ω

2.2 Interface Board

The interface board provides auxiliary devices that are required for standalone operation of the Orion receivers. It comprises

- a switching regulator allowing operation from unregulated power supplies,
- a rechargeable battery to maintain the non-volatile memory and real-time clock during power down times and
- two RS232 serial line drivers for communication with standard peripheral devices.

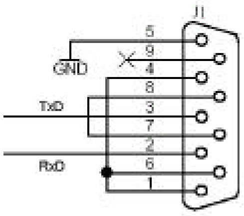
Key parameters of the interface board are summarized in Table 2.2.

Table 2.2 Physical and electrical parameters of GPS Orion interface board

Parameter	Value
Dimension	95mm x 50mm x 20mm
Weight	70g
Operating voltage	8–30V
Efficiency of switching regulator	85%
Total power consumption (I/F and main board)	2.4 W
Battery	+3.6V NiCad, 110 mAh ([1])
I/O ports	2 x RS232 (±10V) Sub-D9 connector (male)

The two serial ports support the ground, receive and transmit line using the standard pin assignment for Sub-D9 connectors (Table 2.2). Pins 7 and 8 are cross-connected since the Orion receiver does not support a hardware handshake. Likewise the three pins 1, 4, and 6 are connected among each other.

Table 2.2 Pin assignment for RS232 Sub-D9 connectors (Port A and B)

Pin	Description	Remarks	Schematic
1	DCD (Data Channel Received Line Signal Detector)	Connected with DTR and DSR (pins 4, 6)	
2	RxD (Receive Data)		
3	TxD (Transmit Data)		
4	DTR (Data Terminal Ready)	Connected with DCD and DSR (pins 1, 6)	
5	GND (Signal Ground)		
6	DSR (Data Set Ready)	Connected with DCD and DTR (pins 1, 4)	
7	RTS (Request to Send)	Connected with CTS (pin 8)	
8	CTS (Clear to Send)	Connected with RTS (pin 7)	
9	RI (Ring Indicator)	Not connected	

2.3 Antenna

The GPS Orion receiver is operated with an active antenna (or a passive antenna and external preamplifier) having a minimum gain of 16 dB and a noise-figure of less than 4 dB More specifically, the ANPC-131 antenna of M/A COM is recommended (cf. [4]), for terrestrial applications. It offers an LNA gain of +26 dB and a 1.5 dB noise-figure at the L1 frequency (1575.42 MHz).

For space applications dedicated antenna designs with heat and vacuum resistant radomes are generally required. For sounding rockets wrap around antennas, helix tip antennas or blade antennas with separate preamplifiers are available on request. GPS antennas for satellite applications are offered by e.g. Sensor Systems Inc.

3. Operations Guide

3.1 Basic Receiver Handling

3.1.1 Hardware Setup

For operating the GPS Orion receiver in a ground based test environment, the following hardware items are typically required:

- Orion main board
- Orion interface board with power cable
- Power supply or battery (typically +12 V, 250 mA)
- Active GPS antenna (ca. 26 dB gain) with cable and SMA (or MCX) connector (male)
- PC with Windows operating system
- Serial interface cable (cross-link with female-female sub-D9 connectors)

Upon first operation, mount the main board on top of the interface board and connect both board via the 9-pin connector. Since the standard interface board provides no PPS interface, pin 10 of the main board (optional) will remain unused in this configuration. Next,

- connect the active antenna to the antenna plug on the main board
- connect port A (left) of the interface board to the PC's COM1 port
- connect blue cable to ground pin of power supply (minus pole of battery)

The receiver will start to operate once the red cable is connected to the plus pole of the power supply.

3.1.2 Precautions

To avoid an undesirable behavior or even destruction of the receiver, the following handling instructions shall be considered:

- The center pin of the antenna connector provides a +5V power supply for the low noise amplifier of an active GPS antenna. To avoid short cuts it is strongly advisable to disconnect the receiver from the power supply prior to (dis-)connecting the antenna or pre-amplifier.
- R/F attenuators between the receiver and the pre-amplifier must be equipped with a DC by-pass to avoid heating of the attenuator or an overload of the receiver's DC power feed.
- Always connect the plus pin of the power supply last and disconnect it first. Otherwise spurious ground connections via the serial cable or the antenna line may keep the receiver unintentionally powered up.

3.1.3 Serial Communication

The Orion-S and -HD receivers use port A (left connector) as the prime port for command input and message output. By default, this port employs the following RS232 communication parameters:

- 19200 baud
- no parity
- 8 data bits
- 1 stop bit
- no handshaking

For proper communication, these values must match the settings of the PC communication port.

While the Orion receiver is most conveniently used via a dedicated monitoring and control program (e.g. OrionMonitor), elementary operations may likewise be carried out via a standard terminal program. As an example, the HyperTerminal program provided with the Windows operating systems can be used to monitor receiver output messages in real-time and to record the data stream to a file. Vice-versa, commands can be loaded to the receiver from pre-configured files or entered via the keyboard. In the latter case, the STX (0x02) and ETX (0x03) characters marking the command start and end can be generated by pressing the CNTL-B and CNTL-C keys, respectively. If desired, consecutive commands may be separated by white space like blanks or line feeds. Please note, that the correct checksum must be provided for each command to allow proper execution.

3.1.4 Start-Up and Initialization

At power-up the receiver performs the following initialization steps:

- The boot loader is executed and the program code is loaded from EPROM to RAM memory.
- If non-volatile memory has been retained since the previous activation, the receiver restores the latest almanac, broadcast ephemerides, ionospheric and UTC parameters, trajectory aiding parameters, as well as the current time.
- If the receiver was temporarily disconnected from the backup power supply or the respective NVM data are corrupted, the time, almanac and trajectory aiding parameters are initialized with hard-coded default data (*Note*: The actual values used for the default initialization depend on the particular software release and may vary between receivers). The ephemeris data are marked as unavailable.
- A boot message identifying the current software version is issued.

Subsequently, the signal tracking is started and the receiver starts outputting a predefined sequence of messages at a 1 Hz rate. The same steps are performed when the reset button on the interface board is pressed.

Depending on its previous usage the receiver should start tracking and deliver navigation fixes between a minimum of 30 s (hot start with known time, position and ephemerides) and a maximum of 15 min (cold start). To speed-up the signal acquisition various commands can be employed to provide the receiver with a priori information. A comprehensive initialization sequence is listed below. Some steps are optional and may be skipped as desired.

- To discard all existing receiver settings issue the CS (cold start) command followed by a reset (or reboot) of the receiver. This will return the receiver into a native state with time, almanac, and trajectory aiding parameters determined by the firmware defaults.
- Set the current date and time (using the SD and ST commands). For static receiver operation an accuracy of 10 min is generally sufficient. For LEO operations and initializations in the free-flight phase of ballistic vehicles a maximum error of 10 s is tolerable.
- For unaided operation, set the geographic coordinates (using the IP command) or the initial state vector (using the PV command). For static receiver operation an accuracy of 1° is generally sufficient and the altitude can be assumed as zero (sea level).
- For aided operation set the trajectory parameters (using the LO command for LEO operations or the LT and ET commands for ballistic trajectories).
- Load a set of current almanac parameters based on e.g. a YUMA almanac (using the LA and F13 commands). If desired, the almanac may be complemented by ionospheric correction data and UTC leap second information (F15 command).

- If the above steps have taken more than two minutes, the receiver may have started to scan through the permitted range of frequency bins. Reset or reboot the receiver to start the signal search in the central frequency bin.
- Select the desired aiding mode (using the AM command).
- Set other operations parameters (e.g. output rates, elevation mask, etc.) as desired.

The receiver should now be indicating proper tracking and a valid 3D navigation fix as part of the periodic navigation and status messages.

3.1.5 Output Selection

The output of the GPS Orion-S/HD receiver can, to a limited degree, be configured according to the user needs. All relevant commands and the available output messages are described in full detail in Chap. 4 of this User’s Guide.

In start-up configuration[1] the receiver outputs an F00 (geodetic) and F40 (Cartesian) navigation message with time, position and velocity as well as the number of tracked satellites once per second. Channel status information is available as part of the F03 or F43 message that is likewise issued at the 1 Hz update rate. Navigation and status data belong to a class of periodic receiver messages that can be controlled using the DR (Data Rate) command. It sets the output interval of a specified message number in multiples of the navigation interval. Furthermore messages can be polled once or disabled completely. The data rate selection is available for the F00/03/04/05/08 WinMon messages (i.e. the standard Mitel message set of the original Orion receiver firmware), the F40/41/42/43/45/46/47/48 WinMon messages (specific for the Orion-S and/or –HD receiver) as well as a limited set of standard and proprietary NMEA type navigation and status messages.

Dedicated commands are available for polling specific configuration and operations parameter on demand. These comprise the SA command (Send Almanac, ephemerides and iono/UTC data), the TA command (Transmit Almanac), the TE command (Transmit Ephemeris), the TO command (transmit orbit) and the TT (Transmit Trajectory) command.

Aside from the periodic and polled outputs, the receiver autonomously issues various messages on the occasion of special events:

- At start-up, a boot message (F99 format) is transmitted that identifies the current software version.
- Upon reception and processing of most commands a response message (F98 format) is issued.
- Broadcast ephemeris parameters (F14 message) are transmitted in the Orion-S at start-up and whenever new values become available as part of the GPS navigation message.

These messages are cannot be deactivated and may result in temporary output buffer overflows, when the communication channel does not provide a sufficient bandwidth for all periodic and non-periodic data.

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[1] On customer request, other default configurations may be implemented in the firmware of project specific software releases.

3.1.6 Pulse-per-Second Signal

Supporting receiver versions provide a one-pulse-per-second signal (CMOS TTL level) at pin 10 of the interface connector. The PPS signal is available in case of valid navigation. It has a one millisecond duration and its starting edge is aligned to the occurrence of an integer GPS second with an accuracy of better than 1 µs. The typical error amounts t ca. 0.2 µs and is determined by the limited resolution of the correlator timing (175 ns) and the accuracy with which the modelled GPS time of the receiver matches the true GPS system time (<0.1 µs with S/A off). When using long antenna cables in ground based tests, the PPS will experience a systematic shift in accord with the added signal time.

Irrespective of the availability of an output pin for the PPS hardware signal, the measurements and navigation solution of the receiver are aligned to the integer GPS second whenever a continuous 3D navigation solution has been achieved.

3.1.7 Troubleshooting

If deemed necessary, various electrical and functional checks may be performed at any time to validate the proper receiver operation:

- The product of the supply voltage and current consumption shall match the nominal power consumption of 2.4±0.1W. A lower value may indicate errors in the boot process caused by e.g. twisted EPROMs or a broken address/data line on the main board.
- When connected to a terminal program, the receiver shall output a continuous stream of (mostly numeric) ASCII characters. Failures to do so may indicate problems with the physical connection (e.g. twisted RX/TX lines of the serial cable) or a wrong configuration (baud rate, etc.) of the PCs COM port.
- The receiver shall respond to commands (for a simple test, try the <STX>DR00-10A<ETX> and <STX>DR000117<ETX> commands to toggle the F00 message output). Failures may again indicate problems with the physical connection or the communication software.
- With adequate open sky visibility the receiver shall achieve code lock (“C”) with an SNR value of better than 10 dB on (at least) one channel within a maximum of 5 min irrespective of its initialization state. Otherwise, problems in the antenna system (passive versus active antenna, inappropriate or erroneously connected pre-amplifier, broken antenna cable, etc.) may be suspected.
- If other problems in the antenna system can be ruled out, one may further verify that the center pin of the antenna connector has a DC level of +5.0±0.1V with respect to ground.

In case of persistent failures inspection by the manufacturer may be required.

3.2 Special Applications

3.2.1 Aiding for Ballistic Trajectories

To allow a rapid acquisition and an optimal channel allocation in case of high vehicle dynamics the Orion-HD receiver can be aided by a priori trajectory information. For sounding rockets or other ballistic missions the nominal flight path is represented by a piecewise, low order polynomial approximation stored within the receiver (Fig. 3.1, [12]). Using this information the GPS satellites in view and the expected Doppler shift can be computed at any time after launch.

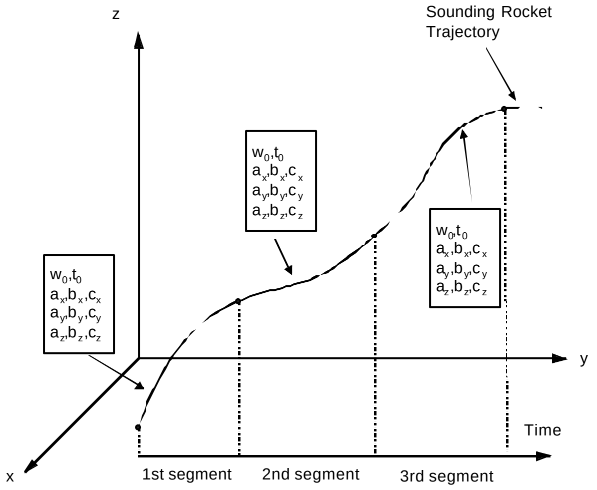

Fig. 3.1 Piecewise polynomial approximation of the reference trajectory of a sounding rocket. Each time interval is represented by its start epoch (GPS week and seconds) and three coefficients per axis.

To minimize the computational workload in each step, a simple 2nd-order polynomial

$$\boldsymbol{r}(t) = \begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} a_x \\ a_y \\ a_z \end{pmatrix} + \begin{pmatrix} b_x \\ b_y \\ b_z \end{pmatrix} (t-t_0) + \begin{pmatrix} c_x \\ c_y \\ c_z \end{pmatrix} (t-t_0)^2 \tag{3.1}$$

is used to approximate the trajectory over discrete time intervals in the WGS84 reference frame. Upon differentiation, one obtains an associated approximation of the instantaneous Earth-fixed velocity vector

$$\boldsymbol{v}(t) = \begin{pmatrix} \dot{x} \\ \dot{y} \\ \dot{z} \end{pmatrix} = \begin{pmatrix} b_x \\ b_y \\ b_z \end{pmatrix} + 2 \begin{pmatrix} c_x \\ c_y \\ c_z \end{pmatrix} (t-t_0) \ , \tag{3.2}$$

which is linear in time. Accordingly, the individual time intervals should be chosen in such a way as to exhibit a near constant acceleration. Up to 15 polynomials can be configured and stored which is sufficient to provide a position accuracy of about 2 km and a velocity accuracy of roughly 100 m/s in representative missions.

Based on the polynomial approximation of the nominal trajectory, the reference position and velocity of the host vehicle are computed once per second. The result is then used to obtain the line-of-sight velocity and Doppler frequency shift for each visible satellite, which in turn serve as initial values for the steering of the delay and frequency locked loops. The position-velocity aiding thus assists the receiver in a fast acquisition or re-acquisition of the GPS signals and ensures near-continuous tracking throughout the boost and free-flight phase of the ballistic trajectory.

The command interface of the Orion-HD receiver supports a total of six different instructions to support the handling of ballistic trajectory information:

- The LT (Load Trajectory) command initiates the upload of a set of trajectory polynomials.
- Each trajectory polynomial is then loaded in the form a single F51 command message.
- The sequence is terminated by the ET (End Trajectory) command.
- The reference epoch for the trajectory polynomials can be configured using the LE (Load Epoch) command, unless it is automatically detected through a hardware lift-off signal (see below).
- Using the TT (Transmit Trajectory) command, the currently loaded trajectory information can be dumped. When issued, the receiver outputs an F50 message providing the reference epoch and sequence of F51 messages containing the individual trajectory polynomials.
- Finally, the aiding can be activated (or deactivated) through the AM (Aiding Mode) command.

Both the reference epoch and the trajectory polynomials are stored in non-volatile memory and made available upon a reboot of the receiver.

The aiding is designed to support a rapid acquisition and re-acquisition after temporary signal losses. It controls the initial configuration of a previously void tracking channel but has no impact on those channels that have already achieved a continuous code and carrier lock and follow the signal dynamics with their respective tracking loops. When aiding is activated, the Doppler and visibility prediction depends only on the a priori trajectory polynomials, and the time since the reference epoch. As such, a faulty or outdated navigation solution has no impact on the initialization of new channels and safe acquisition can even be achieved if during boosted flights that do not allow a linear prediction of the latest state vector. On the other hand, erroneous values may be predicted in case of a major deviation from the nominal flight profile. The choice of aided versus unaided operation must therefore be based on a careful risk assessment. Aiding is clearly advisable, if continued tracking cannot be assured due to e.g. a changing field-of-view or switching between antennas. Unaided operation, on the other hand, may be preferable, if a stable initial acquisition and continued GPS visibility can be assured but the actual flight profile is not know with good confidence before the mission.

3.2.2 Lift-off Signal

The discrete input pin of the GPS Orion-HD main board can be employed to automatically sense the lift-off time of a sounding rocket and set the reference epoch for the trajectory aiding. The lift-off signal is defined to remain low while the rocket is grounded and switch to high level at lift-off. While set to low, the receiver continuously overwrites the reference time for the trajectory polynomials by the current time. This update is performed at each TIC and is thus accurate to about 0.1 s. For proper function, the lift-off signal must remain high throughout the entire flight.

3.2.3 IIP Prediction

The instantaneous impact point (IIP) describes the touch-down point of a sounding rocket under the assumption of an immediate end of the propelled flight. It is representative of a situation in which the rocket motor is instantaneously switched off by the mission control center following e.g. a guidance error during the boost phase. As part of the range safety operations during a sounding rocket launch, a real-time prediction of the IIP is performed to monitor the expected touch down point in case of a boost termination. The computation and display of the IIP allows the range safety officer to discern whether the rocket would eventually land outside the permissible range area and thus necessitate an abort of the boosted flight or even a destruction of the malfunctioning vehicle.

For an optimal support of sounding rockets, the Orion-HD receiver is able to predict the instantaneous impact point (IIP) from its navigations solution. The instantaneous position and velocity are expressed in the local horizontal coordinate system and a plane-Earth parabolic trajectory model with first order corrections for surface curvature, gravity variation and Earth rotation is used to predict the motion up to the intersection with the surface of the Earth [13]. Due to its inherent simplicity the analytical IIP model is well suited for real-time time computations but is still competitive in terms of accuracy. Comparisons have demonstrated that the overall agreement with a full modeling of conservative forces is high enough to introduce IIP prediction errors of less than 1.5% of the ground range for sounding rockets reaching altitudes of up to 700 km and flight times of about 15 min.

In view of negligible processor requirements, the IIP prediction is always performed along with the navigation solution. However, the F47 or $PDLRM,IIP has to be activated (using the DR Data Rate command) to output the geodetic impact point coordinates and the time to impact.

3.2.4 Aiding for LEO Satellites

The Orion-S receiver provides a dedicated aiding mode to support the GPS signal acquisition onboard a low Earth orbiting (LEO) satellite. Similar to the HD receiver, it uses a coarse approximations of the nominal trajectory to forecast the visible GPS satellites and the expected line-of-sight Doppler shift. This information is the used to allocate and initialize new tracking channels. In accord with its primary application area, the Orion-S receiver employs the SGP4 orbit model for LEO satellites [14] to predict the user spacecraft trajectory from NORAD twoline element data sets.

Twoline elements comprise 2 lines of 69 characters each (cf. Table 3.1) to specify the epoch and the orbital elements of a satellite, as well as information on the secular change in the mean motion and on the ballistic coefficient (or the second derivative of the mean motion). They also give the international satellite ID, an element number and a revolution number. Each line contains a checksum at the end to guard against transmission errors.

Table 3.1 Description of the contents of NASA/NORAD 2-line element records

Column	Description Line 1
01-01	Line number of element data
03-07	Satellite number
10-11	International Designator (last two digits of launch year)
12-14	International designator (launch number of year)
15-17	International designator (piece of launch)
19-20	Year of epoch (last two digits)
21-32	t_0; day of epoch (day of year and fractional day)
34-43	$1/2 \cdot dn_0/dt$; the time rate of change in the „mean“ mean motion (in units of [rev/d^2]), or the ballistic coefficient B (depending on ephemeris type)
45-52	$1/6 \cdot d^2n_0/dt^2$; the second time rate of change in the „mean“ mean motion (in units of [rev/d^3]). A decimal point is assumed between columns 45 and 46. Will be left blank if not applicable (see above)
54-61	$B^*=1/2 \cdot B r_0$, where $B=1/2 \cdot C_D \cdot A/m$ is the drag term (in units of [1/R$_\oplus$]; a decimal point is assumed between columns 54 and 55
63-63	Ephemeris type
65-68	Element number
69-69	Check sum for line 1 (modulo 10); numbers count face value, letters and blanks as 0, periods and plus signs as 0, minus signs as 1

Column	Description Line 2
01-01	Line number of element data
03-07	Satellite number
09-16	i_0; the mean inclination (in [°])
18-25	W_0; the mean right ascension of the ascending node (in [°])
27-33	e_0; the mean eccentricity. A decimal point is assumed between columns 26 and 27
35-42	w_0; the mean argument of perigee (in [°])
44-51	M_0; the „mean“ mean anomaly (in [°])
53-63	n_0; the „mean“ mean motion (in [rev/d]) dependent on SGP type
64-68	Revolution number
69-69	Check sum for line 2 (modulo 10)

The orbital elements are mean Keplerian elements (with the number of revolutions per day substituting the semi-major axis), which best represent the actual trajectory when used in combination with the SGP4 (or SDP4) orbit propagators. The SGP4 orbit model was developed in 1970 based on the analytical perturbation theory of Brouwer and accounts for the Earth gravity field through zonal parameters J_2, J_3 and J_4 and the atmospheric drag through a power density function assuming a non-rotating, spherical atmosphere. It is recommended for satellites in near-circular orbits with typical periods of less than 225 min.

Aided operation of the Orion-S receiver is supported by a variety of dedicated commands:

- For configuring the orbital elements of the user satellite, the LO (Load Orbit) command is used. The first and second line of the elements set are each embedded into a separate LO command and consecutively transmitted to the receiver.
- Using the TO (Transmit Orbit) command the currently loaded mean orbital elements can always be dumped in the form of a single F52 output message.
- Aiding is activated (or deactivated) using the AM (Aiding Mode) command.

Upon commanding, a new element set is always stored in non-volatile memory. The information is thus preserved and made available again after a reboot of the receiver. This allows a power saving, intermitted operation, in which the receiver is powered up for only some parts of each orbit.

Use of the aiding mode provides a particularly simple way to initialize the receiver on a LEO satellite, since a single element set is good for initialization at multiple epochs. Typically, the twoline elements are accurate enough to allow aiding for a period of at least one week following their validity epoch. If continuous tracking can be ensured by an appropriate antenna orientation and elevation mask, the receiver may be commanded to unaided mode after successful acquisition of a 3D navigation fix. It will henceforth use the latest navigation solution to forecast the instantaneous visibility conditions and expected Doppler shifts of the GPS satellites.

3.2.5 Relative Navigation

The Orion-S receiver operates a DGPS task providing simple relative navigation of two host vehicles via the exchange of raw navigation solutions. To operate the relative navigation feature, the secondary I/O ports (port B) of two receivers must be connected via a bi-directional serial radio link with a 19.2 kB data rate. On the B port, each receiver outputs an F40 navigation message as well as an F42 raw data message once per second. Vice versa, it decodes F42 messages on input and uses them to compute a differential navigation solution. The remote measurements are differenced against the receiver's own raw data thus eliminating common errors like GPS clock errors, broadcasts ephemeris and to a fair degree ionospheric errors. A differential position is then computed after carrier smoothing of the differenced pseudorange measurements. Likewise, velocity is obtained from differential range rate measurements that are derived from a second order polynomial approximating the differential carrier phases. Further details of the employed algorithms and concepts are provided in [15]. The achieved accuracy amounts to typically 0.5 m in position and 0.5 cm/s velocity.

For orbital applications the resulting relative navigation solution can conveniently be output in a reference frame aligned with the radial, along-track and cross-track direction, but a standard WGS-84 representation is also available. In either case it is necessary to activate the respective output message (F45 or F46) using the DR (Data Rate command). Note that the relative navigation solution is always one second late compared to the standard navigation output to accommodate the required time for exchanging raw measurements via the auxiliary port.

3.2.6 External LNA Power Supply

The antenna line of the Orion GPS receiver provides a +5V DC power level to feed a low noise amplifier with a maximum current consumption of about 50 mA. In some cases this specification may not be appropriate and an external power supply be required. Possible applications include e.g. the use of multiple parallel antennas or the use of miniature antennas with 3.3V LNA. In this case a “bias-T” is employed to block the DC supply of the receiver (via a built-in capacitor) and to insert the external supply voltage (via an R/F isolating inductivity) to the subsequent antenna line. An added advantage of the external DC power supply is the possibility to apply a current limitation and thus protect the receiver front-end against short cuts in the antenna system.

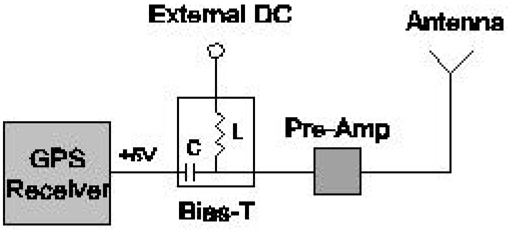

Fig. 3.1 Schematic view of external LNA power supply using a bias-T

A block diagram showing the connection of receiver, bias-T, external supply and pre-amplifier is given in Fig. 3.1. Bias-Ts suitable for GPS frequencies are available from various manufacturers including M/A COM, Pasternak, etc.

4. Command and Output Message Reference

4.1 Overview

A summary of the available commands and output messages for the Orion-HD and –S receivers is provided in the subsequent table:

Table 4.1 GPS Orion commands and output messages

MsgID	*Type*	*Format*	*Receiver*	*Description*
AC	cmd	WinMon	all	All assign PRN to all channels
AM	cmd	WinMon	HD, S	Select aiding mode
CH	cmd	WinMon	all	Set number of active channels
CS	cmd	WinMon	all	Cold start
DR	cmd	WinMon	HD, S	Select the rate of receiver output messages
DS	cmd	WinMon	all	Deselect satellite
DW	cmd	WinMon	HD, S	Set Doppler window
EM	cmd	WinMon	all	Set elevation mask
ET	cmd	WinMon	HD	End of trajectory polynomials
IP	cmd	WinMon	all	Set initial position
LA	cmd	WinMon	all	Load almanacs
LE	cmd	WinMon	HD	Load epoch of trajectory polynomials
LO	cmd	WinMon	S	Load orbital elements
LT	cmd	WinMon	HD	Load trajectory polynomials
MC	cmd	WinMon	HD, S	Select application of media corrections
OE	cmd	WinMon	all	Set oscillator error
PM	cmd	WinMon	all	Set PDOP mask
PV	cmd	WinMon	HD, S	Set initial position and velocity
RH	cmd	WinMon	all	Set reference position to current position
RM (obsolete)	cmd	WinMon	HD, S	Select aiding mode
RP	cmd	WinMon	all	Set reference position
RS	cmd	WinMon	all	Re-select satellite
SA	cmd	WinMon	all	Save almanac
SD	cmd	WinMon	all	Set date
SM	cmd	WinMon	HD, S	Choose between standard and extended Mitel format
SS	cmd	WinMon	all	Select satellite
ST	cmd	WinMon	all	Set time
TA	cmd	WinMon	HD, S	Transmit almanac
TE	cmd	WinMon	S	Transmit ephemeris
TM	cmd	WinMon	all	Select track mode
TO	cmd	WinMon	S	Transmit orbital elements
TT	cmd	WinMon	HD	Transmit trajectory polynomials
UR	cmd	WinMon	HD	Set the navigation solution update rate
F00	out	WinMon(ext)	all	Geographic navigation data (Mitel)
F03	out	WinMon(ext)	all	Channel status (Mitel)
F04	out	WinMon(ext)	all	Satellite summary (Mitel)
F05	out	WinMon	all	Processing status (Mitel)
F08	out	WinMon	all	Operating parameters (Mitel)
F13	out, in	WinMon	all	Satellite almanac data
F14	out, in	WinMon	all	Satellite ephemeris data
F15	out, in	WinMon	all	Ionospheric/UTC model data
F40	out	WinMon	HD, S	Cartesian navigation data
F41	out	WinMon	HD, S	Pseudorange and range-rate (smoothed)
F42	out	WinMon	HD, S	Pseudorange, carrier phase and range rate (raw)
F43	out	WinMon	HD, S	Channel status
F44	out	WinMon	HD, S	Clock data
F45	out	WinMon	S	Relative navigation data (WGS-4 system)
F46	out	WinMon	S	Relative navigation data (RTN frame)
F47	out	WinMon	HD	Instantaneous impact point
F48	out	WinMon	HD, S	Configuration and status parameters

F50	out	WinMon	HD	Reference epoch for trajectory polynomials
F51	out, in	WinMon	HD	Trajectory polynomials
F52	out	WinMon	S	User spacecraft mean elements
F99	out	WinMon	all	Debug strings (log messages, command responses)
$GPGGA	out	NMEA	all	Position data
$PASHR,POS	out	NMEA	HD	Position and velocity data (Ashtech)
$PDLRM,IIP	out	NMEA	HD	Instantaneous impact point
$PDLRM,XSD	out	NMEA	HD	Extended status data
$PDLRM,RAW	out	NMEA	HD	Raw measurement data

4.2 Protocol Description

The Orion-S and –HD receivers employ the Mitel proprietary WinMon format for commands and output messages. In addition, selected NMEA type output messages are supported. Other than in the standard GPS Orion firmware (cf. [2]), the choice of WinMon and/or NMEA messages is not controlled by the discrete input pin (slide switch) but configured by command. If desired, both message types may simultaneously be activated in the output stream.

4.2.1 WinMon Format

A WinMon sentence is basically an ASCII text string composed of a command or message identifier, the data portion and a hexadecimal checksum (Fig. 4.1). The sentence is embedded in a protocol frame made up of an initial Start of Transmission (STX) character (ASCII 0x02) and a terminating End of Transmission (ETX) character (ASCII 0x03).

STX	C	C	x	x	x	x	...	x	x	H	H	ETX

STX	‘F’	n	n	x	x	x	...	x	x	H	H	ETX

C = Alphabetic character (uppercase).
n = Decimal digit (0,…,9)
x = Data field.
H = Hexadecimal checksum character (uppercase).
STX = Start of Transmission (0x02).
ETX = End of Transmission (0x03).

Fig 4.1 WinMon sentence format and protocol frame for command (top) and output messages (bottom)

Command identifiers consist of two uppercase alphabetic characters, while a message identifier is made up of an initial ‘F’ character and a two digit decimal number[2]. The sentence checksum is the hexadecimal representation of the exclusive-or of all the characters in the sentence, excluding the <STX> and <ETX>. All data bytes contained in the data field of the message are printable 7 bit characters (ASCII 32-127).

In extension of the original GPS Orion software, numerous new commands and output sentences have been defined for the Orion-S and –HD receiver. Other than in the default sentences, however, data fields of output messages are *right justified* for improved readability. The format fields shown in the subsequent command and message descriptions illustrate the fixed number of characters reserved for each data item, with “.” denoting the position of the decimal point. Leading digits may be blank and an “s” indicates that the first non-blank character contains the sign of the respective quantity.

---

[2] In extension of this rule, the F13, F14, F15, and F51 formats are jointly used for retrieving and loading specific receiver data (almanac, ephemeris, ionosphere and trajectory parameters). However, these sentences must always follow a specific command (e.g. LA Load Almanacs) to initiate the upload and none of them will be processed on its own.

4.2.2 NMEA Format

For compatibility reasons, a limited set of NMEA output messages is available in the Orion-S and –HD receivers. Even though the NMEA format could likewise be applied for commanding, this option is not presently supported.

According to the NMEA-0183 standard, each message is initiated by a dollar (‘$’) character and terminated by a carriage-return (CR, ASCII 0x13) and line-feed (LF, ASCII 0x10) record delimiter (Fig. 4.2). The message header provides a unique five character identifier, which is separated from the data field by a comma (‘,’). Commas are likewise used to separate individual items in the data field. This is followed by a footer comprising an asterisk (‘*’) and a two character This checksum is calculated as the exclusive-or of all characters in the header and data field, (i.e. in between but excluding the ‘$’ and ‘*’ characters) and expressed in uppercase hex format.

‘$’	**C**	**C**	**C**	**C**	**C**	**‘,’**	**x**	**x**	**x**	**…**	**x**	**x**	**‘*’**	**H**	**H**	**CR**	**LF**

C = Alphabetic character (uppercase).
x = Data field.
H = Hexadecimal checksum character (uppercase).
CR = Carriage return (0x13).
LF = Line feed (0x13).

Fig 4.2 NMEA format definition

Aside from the overall protocol, the NMEA standard specifically defines a set of default messages ($GPxxx) for use in common GPS receivers. Out of these, only the $GPGGA message is presently available in the Orion-S/HD receivers. Manufacturer specific NMEA messages supported by the receiver are designated by a $PASHR (Proprietary Ashtech Response) or $PDLRM (Proprietary DLR Message). In these cases, the first item of the data field is a three character code that further specifies the message contents (e.g. $PDLRM,IIP for instantaneous impact point coordinates).

NMEA messages typically do not provide a date field and are therefore ambiguous with a 24h period. If absolute timing is required, the WinMon messages should be preferred. All time stamps in the NMEA messages are given in hours, minutes, and seconds referred to the UTC system.

4.3 Commands

The GPS Orion receiver scans the primary communication port for WinMon sentences embedded in the <STX>/<ETX> frame and starts the command processing, if the checksum test is passed. Commands that are syntactically correct but do not match a supported command identifier are ignored. In this case an F98 command response giving the current time and and error message

```
E-id-Ignored unsupported command
```

(with *id* denoting the invalid command) is issued to the output.

4.3.1 Basic Receiver Configuration

4.3.1.1 UR – Update Rate

The navigation solution update rate can be selected using the UR command within the limits specified for a given receiver. Upon execution, the revised settings are acknowledged by one of the following command responses:

```
I-UR-Update rate set to 1Hz
I-UR-Update rate set to 2Hz
I-UR-Update rate set to 5Hz
E-UR-Ignored (invalid argument)
```

CmdID	*Chars.*	*Format*	*Description*
UR	**7**		**Update Rate**
	1	x	<STX>
	2	xx	Command Id (=UR)
	1	x	Rate [Hz] (supported values: 1Hz, 2Hz, 5Hz)
	2	xx	Checksum
	1	x	<ETX>

Examples:

`<STX>`**`UR1`**`36<ETX>`	Select 1 Hz navigation solution update rate (default)
`<STX>`**`UR2`**`35<ETX>`	Select 2 Hz navigation solution update rate (optional)
`<STX>`**`UR5`**`32<ETX>`	Select 5 Hz navigation solution update rate (optional)

4.3.1.2 DR – Data Rate

The DR command provides the means for an individual configuration of receiver output messages. Sentences can be deactivated completely, polled once or issued at selected intervals.

CmdID	*Chars.*	*Format*	*Description*
DR	**11**		**Data Rate**
	1	x	<STX>
	2	xx	Command Id (=DR)
	2	xx	Message number
	3	x(xx)	Output interval (-1..127)
	2	xx	Checksum
	1	x	<ETX>

Notes:

- The output interval specifies the time between consecutive messages of the requested frame number in units of the time interval between navigation solutions (i.e. 1 s for 1 Hz version, 0.5 s for 2 Hz version)
- A value of “-1” for the output interval is used to deactivate a given message
- An output interval of “0” requests a one-time output (polling) of the given message
- Negative message numbers control the output of NMEA type message (-1=GPGGA, etc.)

Examples:

<STX>**DR4001**13<ETX>	Issue the F40 navigation message at each update
<STX>**DR43-1**0D<ETX>	Deactivate the F43 channel status message
<STX>**DR480**2A<ETX>	Poll the current configuration and status parameters (F48 msg.)

4.3.1.3 SM – Sentence Mode

The sentence mode command can be used to increase the field width of various Winmon sentences (F00, F03, F04) to accommodate increased altitude, velocity and Doppler values as encountered in typical space applications.

CmdID	*Chars.*	*Format*	*Description*
SM	**7**		**Sentence Mode**
	1	x	<STX>
	2	xx	Command Id (=SM)
	1	x	Sentence Mode (0=Winmon,1=Winmon-X)
	2	xx	Checksum
	1	x	<ETX>

Example:

<STX>**SM0**2E<ETX>	Select standard WinMon format for F00, F03, and F04
<STX>**SM1**2F<ETX>	Select extended WinMon format

4.3.1.4 MC – Media Correction

The MC command controls the application of media corrections to the raw measurements prior to computing the navigation solution. The resulting status of the tropospheric correction switch is confirmed by either of the following command replies:

```
I-MC-Tropospheric correction disabled
I-MC-Tropospheric correction enabled
E-MC-Ignored (invalid argument #1)
```

A second command reply out of

```
I-MC-Ionospheric correction disabled
I-MC-Ionospheric correction enabled
E-MC-Ignored (invalid argument #2)
```

gives the status of the tropospheric correction switch.

CmdID	*Chars.*	*Format*	*Description*
MC	**7**		**Media Correction**
	1	x	<STX>
	2	xx	Command Id (=MC)
	1	x	Tropospheric correction (0=disabled ,1=enabled)
	1	x	Ionospheric correction (0=disabled ,1=enabled)
	2	xx	Checksum
	1	x	<ETX>

Notes:

- Media corrections are applied only to pseudorange measurements but not to range rate data.
- No corrections are applied for GPS satellites below the horizon (0° elevation).
- The tropospheric range correction is altitude dependent and decreases exponentially with a scale height of 7.5 km. It is thus applicable for all types of applications (terrestrial, ballistic, and LEO satellites)
- The ionospheric range delay is computed from the standard Klobuchar model, which can only provide a coarse correction of the true effect. In particular, the model does not depend on the actual altitude of the receiver. For LEO satellite applications, it is recommended to deactivate the ionospheric correction.

Example:

`<STX>`**`MC00`**`0E<ETX>`	Deactivate all corrections
`<STX>`**`MC11`**`0E<ETX>`	Activate all corrections
`<STX>`**`MC10`**`0F<ETX>`	Activate tropospheric correction only

4.3.2 Status Queries

4.3.2.1 TA – Transmit Almanac

The TA command initiates the output of 32 messages (F13) containing the current GPS almanac data.

CmdID	*Chars.*	*Format*	*Description*
TA	**6**		**Transmit Almanacs**
	1	x	<STX>
	2	xx	Command Id (=TA)
	2	xx	Checksum
	1	x	<ETX>

Example:

<STX>**TA**15<ETX>   Dump current almanac

4.3.2.2 TE – Transmit Ephemeris

The TE allows polling of GPS ephemeris data (F14 message) for one or all GPS satellites. In case of an invalid argument the command is ignored and a response

```
I-TE-Ignored (invalid argument)
```

is issued.

CmdID	*Chars.*	*Format*	*Description*
TE	**6**		**Transmit Ephemeris**
	1	x	<STX>
	2	xx	Command Id (=TE)
	2	xx	PRN of selected satellite; 00 requests complete set of 32 ephemerides
	2	xx	Checksum
	1	x	<ETX>

Notes:

- F14 ephemeris messages are also issued automatically, whenever updated GPS data have been extracted from the navigation data stream broadcast by the GPS satellites.

Examples:

<STX>**TE00**11<ETX>   Dump ephemerides for PRN 1 to 32
<STX>**TE28**1B<ETX>Query ephemeris data for PRN 28

4.3.3 Initialization

4.3.3.1 PV – Position-Velocity

The PV command sets the Cartesian position and velocity vector. It should be used instead of the Initial Position (IP) command to initialise the receiver in unaided mode whenever its velocity is larger than 50 m/s.

Execution of the command is acknowledged by an F98 command reply giving the message

```
I-PV-Updated current position and velocity
```

CmdID	*Chars.*	*Format*	*Description*
PV	**72**		**Set initial position and velocity**
	1	x	<STX>
	2	xx	Command Id (=PV)
	11	sxxxxxxxx.x	x [m] (WGS-84)
	11	sxxxxxxxx.x	y [m] (WGS-84)
	11	sxxxxxxxx.x	z [m] (WGS-84)
	11	sxxxxx.xxxx	vx [m/s] (WGS-84)
	11	sxxxxx.xxxx	vy [m/s] (WGS-84)
	11	sxxxxx.xxxx	vz [m/s] (WGS-84)
	2	xx	Checksum
	1	x	<ETX>

Notes:

- Only the position component is stored in NVM.

Example:

<STX>**PV -1075950.9 -5097588.2 +4403281.8 -876.4585 -4848.6594 -5817.7512**1B<ETX>

4.3.3.2 DW – Doppler Window

If code lock for an allocated GPS satellite is not acquired within a given time, the search is extended in neighbouring frequency bins at steps of ±500 Hz. The maximum Doppler offset considered in this search can be specified by the DW command. Its value should account for the expected reference frequency error (±1575 Hz at 1 ppm) and the uncertainty of the predicted Doppler shift. A peak line-of sight velocity of about 1000 m/s is encountered in terrestrial applications, thus requiring an additional ±5 kHz window in cold start tracking mode. For LEO satellites, a window of up to ±40 kHz may be required.

Execution of the command is acknowledged by an F98 command reply of the form

```
I-DW-Changed Doppler window to 11500Hz
```

Negative input values are ignored and an error message

```
E-DW-Ignored (invalid argument)
```

is issued.

CmdID	*Chars.*	*Format*	*Description*
DW	**72**		**Set Doppler window**
	1	x	<STX>
	2	xx	Command Id (=DW)
	5	xxxxx	Doppler search interval [Hz] (±value)
	2	xx	Checksum
	1	x	<ETX>

Notes:

- The specified search window is applied in cold start tracking mode or whenever a navigation fix has not been achieved within the past two minutes. Otherwise a one-bin search in the nominal Doppler window is carried out based on the available position/velocity information and oscillator offset.

Example:

<STX>**DW15000**0E<ETX>	Extend frequency search to ±15 kHz
<STX>**DW0**0E<ETX>	Enforce one-bin Doppler window (requires accurate a priori navigation information and oscillator error knowledge)

4.3.4 Reference Trajectory Aiding

The Orion-S and –HD software versions support a software based aiding of the signal acquisition using reference trajectory information in the form of trajectory polynomials (for ballistic flights) or twoline elements (for satellites in low Earth orbit). Aiding can be controlled by the AM command and various other commands are available to store and retrieve the parameters of the reference trajectory. All relevant data are stored in non-volatile memory during deactivation of the receiver.

4.3.4.1 AM – Aiding Mode

The Aiding Mode command is used to control the application of a priori trajectory information in the Doppler and visibility computation for new tracking channels.

Upon execution of the command an F98 command response with either of the following information or errors messages is issued:

```
I-AM-Aiding disabled
I-AM-Aiding for ballistic trajectories enabled
I-AM-Aiding for low Earth orbits enabled
E-AM-Ignored unsupported aiding mode selection
```

CmdID	*Chars.*	*Format*	*Description*
RM	**7**		**Run Mode**
	1	x	<STX>
	2	xx	Command Id (=AM)
	1	x	Aiding mode (0=unaided,1=ballistic, 2=orbit)
	2	xx	Checksum
	1	x	<ETX>

Notes:

- The Aiding Mode command replaces the obsolete RM (Run Mode) command
- Aiding mode 1 is only available in the Orion-HD receiver, aiding mode 2 is only available in the Orion-S receiver

Examples:

<STX>**AM0**3C<ETX>	Select unaided operation
<STX>**AM1**3D<ETX>	Select aiding for ballistic vehicles using trajectory polynomials
<STX>**AM2**3E<ETX>	Select aiding for LEO satellites using twoline elements

4.3.4.2 RM – Run Mode

The run mode command is a syntactically identical but obsolete command for selecting the aiding mode. It has been superseded by the AM (Aiding Mode) command in software versions D07L (Orion-S) and higher.

Examples:

<STX>**RM0**2F<ETX>	Select unaided operation
<STX>**RM1**2E<ETX>	Select aiding for ballistic vehicles using trajectory polynomials
<STX>**RM2**2D<ETX>	Select aiding for LEO satellites using twoline elements

4.3.4.3 LO – Load Orbit

Twoline orbital elements for aiding the Orion receiver onboard a LEO satellite are loaded using the LO command. One command each is required to upload the first and second line of orbital parameters. Upon successful reception of the first command, an information message

```
I-LO-Twoline elements line 1 received
```

is issued. Upon successful reception of the second command, acceptance of the new element set is confirmed by the message

```
I-LO-Twoline elements line 2 received
```

An inconsistent commanding is reported by an

```
E-LO-Ignored inconsistent twoline elements
```

error message.

CmdID	*Chars.*	*Format*	*Description*
LO	**75**		**Load Orbital Elements**
	1	x	<STX>
	2	xx	Command Id (=LO)
	69	69*x	Twoline elements (line 1 or 2)
	2	xx	Checksum
	1	x	<ETX>

Examples:

```
<STX>LO1 12345U 01999  A 01309.99984954 -.00020228  00000-0 -46117-3 0    0421<ETX>
<STX>LO2 12345  87.0008 134.9419 0012185 296.6516  63.3393 15.42601037    093B<ETX>
```

4.3.4.4 TO – Transmit Orbit

The TO command initiates the output of an F52 message providing the mean orbital elements of the user spacecraft used for receiver aiding in low Earth orbits.

CmdID	*Chars.*	*Format*	*Description*
TO	**6**		**Transmit Orbital Elements**
	1	x	<STX>
	2	xx	Command Id (=TO)
	2	xx	Checksum
	1	x	<ETX>

Example:

<STX>**TO**1B<ETX> Dump current orbital elements

4.3.4.5 LE – Load Epoch

CmdID	*Chars.*	*Format*	*Description*
LE	**25**		**Load Epoch**
	1	x	<STX>
	2	xx	Command Id (=LE)
	4	xxxx	Year
	2	xx	Month
	2	xx	Day
	2	xx	Hours
	2	xx	Minutes
	4	xx.x	Seconds
	3	xxx	Time system (UTC, GPS)
	2	xx	Checksum
	1	x	<ETX>

4.3.4.6 LT – Load Trajectory

CmdID	*Chars.*	*Format*	*Description*
LT	**6**		**Load Trajectory**
	1	x	<STX>
	1	x	<STX>
	2	xx	Command Id (=LT)
	2	xx	Checksum
	1	x	<ETX>

4.3.4.7 ET – End Trajectory

The sequence of trajectory polynomials is terminated by the ET command

CmdID	*Chars.*	*Format*	*Description*
ET	**6**		**End Trajectory**
	1	x	<STX>
	2	xx	Command Id (=ET)
	2	xx	Checksum
	1	x	<ETX>

Example:

<STX>**ET**11<ETX> Dump current reference trajectory

4.3.4.8 TT – Transmit Trajectory

The TE command initiates the output of the reference epoch and the trajectory polynomials uswed for aiding of ballistic vehicles.

CmdID	*Chars.*	*Format*	*Description*
TT	**6**		**Transmit Trajectory**
	1	x	<STX>
	2	xx	Command Id (=TT)
	2	xx	Checksum
	1	x	<ETX>

Example:

<STX>**TT**00<ETX> Dump current reference trajectory

4.4 Output Messages (WinMon Format)

4.4.1 Periodic Receiver Data

4.4.1.1 F00 – Geographic Navigation Data (Mitel)

See [2] for a complete message description.

4.4.1.2 F03 – Channel Status Data (Mitel)

See [2] for a complete message description.

4.4.1.3 F04 – Satellite Summary (Mitel)

See [2] for a complete message description.

4.4.1.4 F05 – Processing Status (Mitel)

See [2] for a complete message description.

4.4.1.5 F08 – Operating Parameters (Mitel)

See [2] for a complete message description.

4.4.1.6 F40 – Cartesian Navigation Data

The F40 message provides the Cartesian state vector (position and velocity) of the host vehicle in the Earth-fixed WGS84 system. It is aligned to the instance of an integer GPS second once the receiver has a achieved continuous 3D navigation fix.

MsgID	Chars.	Format	Description
F40	**104**		**Cartesian navigation data**
	1	x	<STX>
	3	xxx	Message Id (=F40)
	4	xxxx	GPS week
	12	xxxxxx.xxxxx	GPS seconds of week [s] (of navigation solution)
	2	xx	GPS-UTC [s]
	12	sxxxxxxxx.xx	x (WGS84) [m]
	12	sxxxxxxxx.xx	y (WGS84) [m]
	12	sxxxxxxxx.xx	z (WGS84) [m]
	12	sxxxxx.xxxxx	vx (WGS84) [m]
	12	sxxxxx.xxxxx	vy (WGS84) [m]
	12	sxxxxx.xxxxx	vz (WGS84) [m]
	1	x	Navigation status (0=no-Nav,2=3D-Nav)
	2	xx	Number of tracked satellites
	4	xx.x	PDOP
	2	xx	Checksum
	1	x	<ETX>

Example:

```
<STX>F401139180006.0000013 -1070289.69 -1135280.39 +6636840.38 -3777.36103 -6389
.28606 -1696.253242 9 2.172<ETX>
```

4.4.1.7 F41 – Pseudorange and Range Rate (Smoothed)

Carrier phase smoothed pseudoranges and carrier phase based range rate measurements for each of the twelve channels are provided in the F41 message. The data are identical to those employed by the receiver in the computation of the navigation solution for the same epoch.

MsgID	Chars.	Format	Description
F41	**337**		**Pseudorange and range rate (smoothed)**
	1	x	<STX>
	3	xxx	Message Id (=F41)
	4	xxxx	GPS week
	12	xxxxxx.xxxxx	GPS seconds of week [s] (GPS time of observ. using current clock model)
	2	xx	GPS-UTC [s]
	12	xxxxxx.xxxxx	TIC time [s]
			Repeated for each of 12 channels
	2	xx	PRN
	13	xxxxxxxxxx.xx	Pseudorange [m] (smoothed)
	9	sxxxxx.xx	Range rate [m/s] (from carrier phase)
	1	x	Validity flag
	2	xx	Checksum
	1	x	<ETX>

Notes:

- Due to carrier phase smoothing, the pseudoranges provided in the F41 message exhibit a smaller short term noise (ca. 0.1 m) than the raw pseudorange measurements (ca. 1 m; provided in F42). Absolute errors are of similar size, however, due the code-carrier divergence in dispersive media (ionosphere) that necessitates regular resets of the filter/smoother.
- The range rate measurements are obtained by fitting a quadratic polynomial to three adjacent carrier phase measurements over an interval of 2 x 0.1 s and evaluating its derivative at the latest instant. This procedure is rigorously correct up to constant line-of-sight accelerations and is also well applicable for low-Earth orbiting satellites. Some errors may, however, arise in phases of extreme jerk that are e.g. encountered during sounding rocket missions.
- Measurements are nominally collected once full frame lock has been achieved on the tracking channel. In addition, measurements can already be provided in carrier lock if a valid navigation solution is available to perform the required synchronization of raw correlator readings. To prevent bad measurements from entering the navigation solution, measurements are only tagged valid from 10 s after frame lock onwards in the Orion-S receiver.

Example:

```
<STX>F411079482689.0000013  6684.19332 3  20046984.19 -2011.46110  23977589.65 +
6925.48117  21815655.29 +5625.87126  24265035.99 +7015.39122         0.00    +0.
001 2  27964124.58  -140.94113         0.00    +0.00118  25350034.35 –4207.27119
        0.00    +0.001 1  23326544.73  -703.39121  26574208.50  -758.06115
   0.00    +0.00147<ETX>
```

4.4.1.8 F42 – Pseudorange, Carrier Phase and Range Rate (Raw)

Complementary to the smoothed measurements given in the F41 message, the F42 message provide the unprocessed, raw pseudorange, carrier phase and range rate (Doppler) measurements for the 12 tracking channels. All measurements are given in metric units (i.e. [m], [m/s]).

MsgID	Chars.	Format	Description
F42	**505**		**Pseudorange, carrier phase and range rate (raw)**
	1	x	<STX>
	3	xxx	Message Id (=F42)
	4	xxxx	GPS week
	12	xxxxxx.xxxxx	GPS seconds of week [s] (GPS time of observ. using current clock model)
	2	xx	GPS-UTC [s]
	12	xx.xxxxxxxxx	Clock offset [s]
			Repeated for each of 12 channels
	2	xx	PRN
	13	xxxxxxxxxxx.xx	Pseudorange [m] (unsmoothed)
	14	sxxxxxxxxxxx.xx	Integrated carrier-phase [m]
	9	sxxxxx.xx	Range rate [m/s]
	1	x	Validity flag
	2	xx	Checksum
	1	x	<ETX>

Notes:

- The time tag of the measurements is identical to that of the associated navigation data message. It is referred to a model clock that is continuously adjusted to GPS time as part of the navigation solution. In an S/A free environment, this model clock usually deviates by no more than 30 (0.1 µs) from the true GPS time.
- Representative accuracies amount to 0.4 m (pseudodrange), 0.7 mm (carrier phase) and 8 cm/s (Doppler based range rate) for the Orion-S receiver. The HD version exhibits a higher noise of the code (ca. 1 m), carrier phase (ca. 1.5 mm) and Doppler measurements (ca. 30 cm/s) due to the relaxed loop bandwidths.
- Measurements are nominally collected once full frame lock has been achieved on the tracking channel. In addition, measurements can already be provided in carrier lock if a valid navigation solution is available to perform the required synchronization of raw correlator readings. To prevent bad measurements from entering the navigation solution, measurements are only tagged valid from 10 s after frame lock onwards in the Orion-S receiver.

Example:

```
<STX>F421139172840.0000013 0.071561082 3  24651987.05   -307413.396 -3259.220 5
 23960883.83   +105549.919 +2365.530 6  22747854.11-111711119.850 +7410.090 9  2
2493872.10   -380366.985 -4080.44121  24261196.28   -628217.740 -6951.55118  228
61450.35   -333623.542 -6709.47123  23713839.06-113242044.709 -4595.36125  23786
025.64-111954989.319 +5637.95029  22797343.88-112616306.585  +926.33114  2158937
7.48   -162108.043 -1689.34115  20050705.60-114318812.585 -3365.58117  19685814.
19-113949616.991 -1146.1614A<ETX>
```

4.4.1.9 *F43 – Channel Status*

The F43 message indicates the current tracking status of each channel. It provides information on the predicted and measured Doppler shift, the signal-to-noise ratio and the currently achieved lock status. The time tag of the channel status message refers to the instance of message generation and is typically 0.2 s late with respect to the navigation and raw data time tag.

MsgID	Chars.	Format	Description
F43	**253**		**Channel status**
	1	x	<STX>
	3	xxx	Message Id (=F43)
	4	xxxx	GPS week
	8	xxxxxx.x	GPS seconds of week [s] (at message generation time)
	2	xx	GPS-UTC [s]
	4	xxxx	Almanac week
	6	xxxxxx	Time of applicability [s]
	2	xx	PRN of last almanac frame
	1	x	Track mode (1=HighElev,2=SatSel,3=ColdStart)
	1	x	Navigation status (0=no-Nav,2=3D-Nav)
	2	xx	Number of tracked satellites
			Repeated for each of 12 channels
	2	xx	PRN
	6	sxxxxx	Satellite Doppler (predicted) [Hz]
	6	sxxxxx	NCO [Hz]
	1	x	Subframe
	1	x	Lock indicator (c,C,B,F/f)
	2	xx	Carrier-to-noise ratio C/N_0 [db-Hz] (Orion-S) or Signal-to-noise ratio SNR [db] (Orion-HD)
	2	xx	Checksum
	1	x	<ETX>

Notes:

- The lock indicators have the following meaning:

c	Code lock has been achieved
C	Carrier lock has been achieved
B	Bit lock has been achieved
F/f	Frame lock has been achieved

  After successful completion of the code search, the receiver locks to the carrier frequency using a frequency-locked loop (FLL). It transitions to the phase-locked loop (PLL) once the bit synchronization has been achieved and further synchronizes the tracking to the frame start of the GPS navigation data stream. Measurements are typically collected after acquisition of full frame lock, but a "fast lock" mode is also available. It provides valid measurements if only code and carrier lock have been achieved so far on the specific channel, auxiliary synchronization information can be derived from a current (or recent) navigation solution.

  The occurrence of a lower case "f" value for the lock status indicates that the receiver has adjusted the measured phase on this channel by half a cycle to ensure a consistent relation between carrier phase, data bit and frame header words across all channels and different receivers. Resolution of the half-cycle ambiguity is presently only provided for the Orion-S version.

- The Signal-to-noise ratio (SNR, in [dB]) measures the ratio of the post-correlation IQ-vector power (obtained from 1 ms accumulations) and the predicted noise power for a random input signal (assuming nominal AGC operation). The Carrier-to-noise ratio (C/N_0 in [db-Hz]), in contrast measures the post-correlation carrier-to-noise ratio in a 1 Hz bandwidth and is obtained from the statistical distribution of wideband (1 ms) and narrowband (20 ms) IQ-vector powers during 1 s intervals. Both values are empirically related by the expression

$$C/N_0\ [\text{db-Hz}] = 41.5 + 1.1\cdot\ (\text{SNR}\ [\text{db}] - 13.0)$$

which is also used to compute C/N_0 values prior to frame lock. SNR values obtained with representative antenna systems range from a minimum of 5 dB to a maximum of 20 dB. This corresponds to C/N_0 values between 33 dB-Hz and 49 dB-Hz, respectively.

Example:

```
<STX>F431139172840.21311394751361112 8 3 17210 171211f 9 5-12338-124331F11 6-388
49-389461f14 9 21534 214381F1421 36629 365281f1218 35348 352510f1423 24233 24141
1f1225-29538-296291f1129 -4790 -48721f1414  8956  88701f1615 17753 176711f1917
6080  60081F197F<ETX>
```

4.4.1.10 F44 – Clock Data

This message provides information related to the receiver internal clock model.

MsgID	Chars.	Format	Description
F44	**71**		**Clock data**
	1	x	<STX>
	3	xxx	Message Id (=F44)
	4	xxxx	GPS week
	12	xxxxxx.xxxxx	GPS seconds of week [s] (at message generation time)
	2	xx	GPS-UTC [s]
	8	xxxxxxxx	TIC count
	8	xxxxxxxx	Real Time Clock count [s]
	4	xxxx	Extrapolated boot time (GPS week)
	12	xxxxxx.xxxxx	Extrapolated boot time (GPS seconds of week) [s]
	6	sx.xxx	Clock drift [µs/s]
	8	xxxxxxxx	Time of applicability of clock model (TIC)
	2	xx	Checksum
	1	x	<ETX>

Notes:

Message definition subject to revision.

Example:

```
<STX>F441079479659.8000013   36550    35561079476004.72446+0.418   3654240<ETX>
```

4.4.1.11 F45– Relative Navigation Data (WGS-84 System)

MsgID	Chars.	Format	Description
F45	**104**		**Relative navigation data (WGS-84 system)**
	1	x	<STX>
	3	xxx	Message Id (=F45)
	4	xxxx	GPS week
	12	xxxxxx.xxxxx	GPS seconds of week [s] (of navigation solution)
	2	xx	GPS-UTC [s]
	12	sxxxxxxxx.xx	$D\mathbf{r}_x$ (x position difference remote–local) [m]
	12	sxxxxxxxx.xx	$D\mathbf{r}_y$ (y position difference) [m]
	12	sxxxxxxxx.xx	$D\mathbf{r}_z$ (z position difference) [m]
	12	sxxxxx.xxxxx	$D\mathbf{v}_x$ (x velocity difference remote–local) [m]
	12	sxxxxx.xxxxx	$D\mathbf{v}_y$ (y velocity difference) [m]
	12	sxxxxx.xxxxx	$D\mathbf{v}_z$ (z velocity difference) [m]
	1	x	Navigation status (0=no-Nav,2=3D-Nav)
	2	xx	Number of tracked satellites (remote receiver)
	4	xx.x	PDOP (remote receiver)
	2	xx	Checksum
	1	x	<ETX>

Example:

```
<STX>F451139172978.0000013        +653.26       +2342.55     -11667.94       +0.26231
+13.04631    +2.648422 6 2.66A<ETX>
```

4.4.1.12 F46 – Relative Navigation Data (RTN Frame)

MsgID	Chars.	Format	Description
F46	**104**		**Relative navigation data (RTN frame)**
	1	x	<STX>
	3	xxx	Message Id (=F46)
	4	xxxx	GPS week
	12	xxxxxx.xxxxx	GPS seconds of week [s] (of navigation solution)
	2	xx	GPS-UTC [s]
	12	sxxxxxxxx.xx	$D\mathbf{r}_\mathrm{R}$ (radial position difference; local-remote) [m]
	12	sxxxxxxxx.xx	$D\mathbf{r}_\mathrm{T}$ (along-track position difference) [m]
	12	sxxxxxxxx.xx	$D\mathbf{r}_\mathrm{N}$ (cross-track position difference) [m]
	12	sxxxxx.xxxxx	$D\mathbf{v}_\mathrm{R}$ (radial velocity difference; local-remote) [m]
	12	sxxxxx.xxxxx	$D\mathbf{v}_\mathrm{T}$ (along-track velocity difference) [m]
	12	sxxxxx.xxxxx	$D\mathbf{v}_\mathrm{N}$ (cross-track velocity difference) [m]
	1	x	Navigation status (0=no-Nav,2=3D-Nav)
	2	xx	Number of tracked satellites (remote receiver)
	4	xx.x	PDOP (remote receiver)
	2	xx	Checksum
	1	x	<ETX>

Example:

```
<STX>F461139172978.0000013      -12.20   -11918.68       -0.00    -0.01829    +0
.01417    -0.003602 6 2.673<ETX>
```

4.4.1.13 F47 – IIP Prediction

MsgID	Chars.	Format	Description
F47	**52**		**IIP prediction**
	1	x	<STX>
	3	xxx	Message Id (=F48)
	4	xxxx	GPS week
	12	xxxxxx.xxxxx	GPS seconds of week [s] (at output)
	2	xx	GPS-UTC [s]
	1	x	Blank
	9	sxxx.xxxx	Longitude [deg]
	1	x	Blank
	8	sxx.xxxx	Latitude [deg]
	1	x	Blank
	6	xxxx.x	Time to impact [s]]
	1	x	Validity flag (0= no IIP pred. available, 1=valid IIP pred. available)
	2	xx	Checksum
	1	x	<ETX>

Example:

```
<STX>F471195 45245.5000013  -43.9531  -2.2042  211.3163<ETX>
```

4.4.1.14 F48 – Configuration and Status Parameters

MsgID	Chars.	Format	Description
F48	**48**		**Configuration and status parameters**
	1	x	<STX>
	3	xxx	Message Id (=F48)
	4	xxxx	GPS week
	8	xxxxxx.x	GPS seconds of week [s] (at output)
	2	xx	GPS-UTC [s]
	4	xxxx	Almanac week
	5	sxxxx	Doppler offset [Hz]
	1	x	Mode (0=default,1=rocket,2=orbit)
	1	x	Output format (0=default,1=extended)
	1	x	Update rate of navigation and display task [Hz] (1Hz, 2Hz, 5Hz)
	2	xx	Spare CPU capacity [%]
	3	sxx	Elevation mask [deg]
	2	xx	PDOP mask
	8	xxxxxx.x	Launch time (GPS seconds of week [s])
	2	xx	Checksum
	1	x	<ETX>

Example:

```
<STX>F481139216000.1131139  23300226  099216000.17C<ETX>
```

4.4.2 Working Parameters

4.4.2.1 F50 – Reference Epoch for Trajectory Polynomials

MsgID	Chars.	Format	Description
F50	**24**		**Reference epoch for trajectory polynomials**
	1	x	<STX>
	3	xxx	Message Id (=F50)
	4	xxxx	Year
	2	xx	Month
	2	xx	Day
	2	xx	Hours
	2	xx	Minutes
	4	xx.x	Seconds
	3	xxx	Time system indicator (GPS or UTC)
	1	x	<ETX>

Example:

```
<STX>F502003 4 1 52813.2UTC04<ETX>
```

4.4.2.2 F51 – Trajectory Polynomials

MsgID	Chars.	Format	Description
F51	**118**		**Trajectory polynomials**
	1	x	<STX>
	3	xxx	Message Id (=F51)
	2	xx	Running index of polynomial (0..9)
	10	sxxxxx.xxx	t_0 ([s] since reference epoch)
	11	sxxxxxxxx.x	a_x [m] (WGS-84)
	11	sxxxxx.xxxx	b_x [m/s] (WGS-84)
	11	sxxx.xxxxxx	c_x [m/s^2] (WGS-84)
	11	sxxxxxxxx.x	a_y [m] (WGS-84)
	11	sxxxxx.xxxx	b_y [m/s] (WGS-84)
	11	sxxx.xxxxxx	c_y [m/s^2] (WGS-84)
	11	sxxxxxxxx.x	a_z [m] (WGS-84)
	11	sxxxxx.xxxx	b_z [m/s] (WGS-84)
	11	sxxx.xxxxxx	c_z [m/s^2] (WGS-84)
	2	xx	Checksum
	1	x	<ETX>

Example:

```
<STX>F51 0    +0.000 +2245875.5   +11.8606  +2.599629  +866832.3    +7.7294  +0.
602120 +5886908.8   -11.8314 +12.4239247F<ETX>
```

4.4.2.3 F52 – User Spacecraft Mean Elements

MsgID	Chars.	Format	Description
F52	**95**		**User spacecraft mean elements**
	1	x	<STX>
	3	xxx	Message Id (=F52)
	4	xxxx	GPS week of epoch
	11	xxxxxxx.xxx	GPS seconds of week [s] of epoch
	11	xxxxxx.xxxx	SGP4 mean semi-major axis a [km]
	11	xx.xxxxxxxx	SGP4 mean eccentricity e
	9	xxxxx.xxxx	SGP4 mean inclination i [deg]
	10	xxxxx.xxxx	SGP4 mean right ascension of ascending node Ω [deg]
	10	xxxxx.xxxx	SGP4 mean argument of perigee ω [deg]
	10	xxxxx.xxxx	SGP4 mean mean anomaly M [deg]
	12	xxx.xxxxxxxx	SGP4 ballistic coefficient B
	2	xx	Checksum
	1	x	<ETX>

Example:

```
<STX>F521079 475200.000  6933.6698 0.00108870  97.6045  143.0131  277.5609   82.
4397 -0.003070225C<ETX>
```

4.4.3 Diagnosis Messages

4.4.3.1 F98 – Command Response

MsgID	Chars.	Format	Description
F98	**var**		**Command Response**
	1	x	<STX>
	3	xxx	Message Id (=F98)
	4	xxxx	GPS week
	8	xxxxxx.x	GPS seconds of week [s] (at output)
	1	x	Dash (“-“)
	1	x	Message type (I=Info, W=Warning, E=Error)
	1	x	Dash (“-“)
	2	xx	Command ID
	1	x	Dash (“-“)
	var		Text
	2	xx	Checksum
	1	x	<ETX>

Examples:

```
<STX>F981139172809.2-I-MC-Ionospheric correction enabled1C<ETX>
<STX>F981139172809.2-E-XX-Ignored unknown command6F<ETX>
```

4.5 Output Messages (NMEA Format)

4.5.1 $PASHR,POS Navigation Data

The $PASHR,POS sentence provides the position and velocity fix as well as the satellite tracking status. The following specification describes only those fields supported by the Orion GPS receiver implementation of the $PASHR,POS message.

If a 3-D navigation fix has been achieved the following sentences is sent out:

Quantity	Format	Units	# of Chars	Range
Sentence identifier	CCCCC		5	'PASHR'
single comma	C		1	','
Secondary identifier	CCC		3	'POS'
single comma	C		1	','
Raw/differential position	C	(see note 1)	1	'0' or '1'
single comma	C		1	','
Satellites used in Nav fix	XX		2	00 -> 12
single comma	C		1	','
UTC (time) of position	hhmmss.ss	h = hours (int) m = minutes (int) s = seconds (float)	9	000000.00 to 235959.99
single comma	C		1	','
Latitude	ddmm.mmmmm	d = degree (int) m = minutes (float)	10	0000.00000 to 8959.99999
single comma	C		1	','
Latitude Direction	C		1	'N' or 'S'
single comma	C		1	','
Longitude	dddmm.mmmmm	d = degree (int) m = minutes (float)	11	00000.00000 to 17959.99999
single comma	C		1	','
Longitude Direction	C		1	'E' or 'W'
single comma	C		1	','
Altitude above/below WGS84 Earth ellipsoid	±FFFFF.FF	(see note 2)	9	
two commas	CC		2	',,'
Heading	FFF.FF	degrees	6	000.00 -> 359.99
single comma	C		1	','
Speed over ground	FFF.FF	knots	6	000.00 -> 999.99
single comma	C		1	','
Rate of climb	±FFF.FF	m/s	7	-999.99 -> 999.99
single comma	C		1	','
PDPO	FF.F		4	0 -> 99.9
four commas	CCCC		4	',,,,'
S/W Config Code	CCCC		4	'xxxx'

Nominal number of characters (including sentence header and trailer) = 97 + 6 = 103. In sounding rocket applications a typical message length of 105 characters is achieved.

Notes:

1) Raw/differential position 0 = Position is not differentially corrected
   1 = Position is differentially corrected with RTCM format
2) Data field is extended by one character for altitudes above 100km.
3) Data field is extended by one character for vertical velocities above 1000m/s.

Example:

$PASHR,POS,0,08,120210.00,6801.29229,N,02103.64356,E,+313516.69,,351.76,193.33,+2595.47,02.2,,,,D06E*26<CR><LF>

If no navigation fix is available (e.g. due to an insufficient number of tracked satellites) a reduced sentence is transmitted:

Quantity	Format	Units	# of Chars	Range
Sentence identifier	CCCCC		5	'PASHR'
single comma	C		1	','
Secondary identifier	CCCC		3	'POS'
single comma	C		1	','
Not used	C		1	'0'
single comma	C		1	','
Satellites used in Nav fix	XX		2	00 -> 12
single comma	C		1	','
Current receiver time	hhmmss.ss	h = hours (int) m = minutes (int) s = seconds (float)	9	000000.00 to 235959.99
Commas	CCCCCCCCCCCCCC		14	',,,,;,,,,,,,,,'
S/W Config Code	CCCC		4	'xxxx'

Total number of characters (including sentence header and trailer) = 42 + 6 = 48

Example:

$PASHR,POS,0,02,174637.07,,,,,,,,,,,,,,D06E*08<CR><LF>

4.5.2 $PDLRM,IIP Instantaneous Impact Point Data

The $PDLRM,IIP sentence provides the predicted instantaneous impact point and time to impact.

If valid navigation data are available and a prediction for the impact point is computed then the following sentence is generated:

Quantity	Format	Units	# of Chars	Range
Sentence identifier	CCCCC		5	'PDLRM'
single comma	C		1	','
Secondary identifier	CCC		3	'IIP'
single comma	C		1	','
UTC (time) of current IIP predition	hhmmss.ss	h = hours (int) m = minutes (int) s = seconds (float)	9	000000.00 to 235959.99
single comma	C		1	','
IIP validity flag	C	(see note 1)	1	'1'
single comma	C		1	','
Latitude of predicted IIP	ddmm.mmmm	d = degree (int) m = minutes (float)	9	0000.0000 to 8959.9999
single comma	C		1	','
Latitude Direction of predicted IIP	C		1	'N' or 'S'
single comma	C		1	','
Longitude of predicted IP	dddmm.mmmm	d = degree (int) m = minutes (float)	10	00000.0000 to 17959.9999
single comma	C		1	','
Longitude Direction of predicted IIP	C		1	'E' or 'W'
single comma	C		1	','
Predicted time to impact	FFFF.FF	seconds	7	0000.00 -> 9999.99

Nominal number of characters (including sentence header and trailer) = 54 + 6 = 60

Notes:

1) IIP Validity flag: 0 = No IIP prediction computed due to missing navigation data.
1 = Valid IIP data

Example:

`$PDLRM,IIP,120210.00,1,6834.1988,N,02045.0462,E,0629.76*13<CR><LF>`

If no valid navigation fix is available for an IIP prediction a reduced sentence is transmitted:

Quantity	Format	Units	# of Chars	Range
Sentence identifier	CCCCC		5	'PDLRM'
single comma	C		1	','
Secondary identifier	CCC		3	'IIP'
single comma	C		1	','
Current receiver time	hhmmss.ss	h = hours (int) m = minutes (int) s = seconds (float)	9	000000.00 to 235959.99
single comma	C		1	','
IIP validity flag	C	(see note 1)	1	'0'
Commas	CCCCCC		6	,,,,,,'

Total number of characters (including sentence header and trailer) = 27 + 6 = 33

Notes:

1) IIP Validity flag: 0 = No IIP prediction computed due to missing navigation data.
1 = Valid IIP data

Example:

```
$PDLRM,IIP,000037.40,0,,,,,,*25<CR><LF>
```

4.5.3 $PDLRM,XSD Extended Status Data

The $PDLRR,XSD sentence contains channel and receiver status information.

Quantity	Format	Units	# of Chars	Range
Sentence identifier	CCCCC		5	'PDLRM'
single comma	C		1	','
Secondary identifier	CCC		3	'XSD'
single comma	C		1	','
UTC (time)	hhmmss.ss	h = hours (int) m = minutes (int) s = seconds (float)	9	000000.00 to 235959.99
single comma	C		1	','
Current Date	ddmmyy	d = day (int) m = month (int) y = year (float)	6	010100 to 311299
single comma	C		1	','
Track Mode	C	(see note 1)	1	'1' , ‘2’ or ‘3’
single comma	C		1	','
Navigation Status	C	(see note 2)	1	'0' or ‘2’
single comma	C		1	','
Doppler Offset	±XXXX	Hz	5	-9999 to +9999
single comma	C		1	','
Elevation Mask	±XX	[deg]	3	-90 to +90
single comma	C		1	','
Spare CPU Capacity	XX	%	2	00 to 99
single comma	C		1	','
Launch Time	hhmmss.ss	h = hours (int) m = minutes (int) s = seconds (float)	9	000000.00 to 235959.99
Repeated for each of 12 channels				
single comma	C		1	','
PRN	XX		2	00 to 32
single comma	C		1	','
Lock Indicator	C	(see note 3)	1	‘-‘, 'c' , ‘C’, ‘B’ or ‘F’
single comma	C		1	','
Signal-Noise Ratio	XX	dB	2	00 to 99

Nominal number of characters (including sentence header and trailer) = 149 + 6 = 155

Notes:

1) Satellite Selection Mode
1 = Highest elevation
2 = User selected
3 = Cold start mode

2) Navigation Status
0 = No navigation
2 = 3D navigation

3) Satellite Selection Mode
‘-‘ = Unlocked
‘c’ = Carrier lock
‘C’ = Code lock
‘B’ = Bit lock
‘F’ = Frame lock

Example:

```
$PDLRM,XSD,120210.60,061101,1,2,+0264,+00,29,120210.60,08,F,13,07,F,13,09,F,15,1
1,F,09,18,F,16,23,F,15,31,c,03,21,F,14,26,c,14,02,c,14,28,F,19,29,-,02*6F<CR><LF>
```

4.5.4 $PDLRM,RAW Raw Measurement Data

The $PDLRR,RAW sentence contains carrier phase smoothed pseudorange and range rate data.

Quantity	Format	Units	# of Chars	Range
Sentence identifier	CCCCC		5	'PDLRM'
single comma	C		1	','
Secondary identifier	CCC		3	'RAW'
single comma	C		1	','
UTC (time)	hhmmss.ss	h = hours (int) m = minutes (int) s = seconds (float)	9	000000.00 to 235959.99
single comma	C		1	','
GPS week	XXXX	GPS weeks	4	0000 to 9999
single comma	C		1	','
GPS seconds in week	FFFFFF.FFFFF	seconds	12	000000.00000 to 604799.99999
single comma	C		1	','
GPS to UTC time difference	XX	seconds	2	'00' or ‘99’
single comma	C		1	','
Receiver clock offset	±F.FFFFFFFFF	seconds	12	-9.999999999 to +9.999999999
Repeated for each of 12 channels				
single comma	C		1	','
PRN	XX		2	00 to 32
single comma	C		1	','
Smoothed pseudorange	FFFFFFFF.FF	meter	11	00000000.00 to 99999999.99
single comma	C		1	','
Range rate from carrier phases	±FFFF.FF	meter/secs	8	-9999.99 to +9999.99
single comma	C		1	','
Health and validity flag	X	(see note 1)	1	‘0’ or ‘1’

Nominal number of characters (including sentence header and trailer) = 365 + 6 = 371

Notes:

1)	Health and validity flag	0 = SV not used for navigation fix computation 1 = SV used for navigation solution

Example:

```
$PDLRM,RAW,120210.50,1139,216143.50000,13,+0.053943243,08,23530663.74,+0017.80,1
,07,23708751.21,-1442.61,1,09,22500893.52,-1919.70,1,11,24611213.23,-1019.06,1,1
8,22338706.68,-1420.92,1,23,22919032.93,-0825.86,1,00,00000000.00,+0000.00,0,21,
23764439.41,-1513.47,1,00,00000000.00,+0000.00,0,00,00000000.00,+0000.00,0,28,20
852558.36,-1983.40,1,00,00000000.00,+0000.00,0*36<CR><LF>
```

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